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A COMPETITIVE
ASSESSMENT
OF SELECTED

ORIGINAL

REINFORCED COMPOSITE FIBERS



U.S. DEPARTMENT OF COMMERCE
International Trade Administration • Washington, D.C.

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A COMPETITIVE ASSESSMENT
OF SELECTED REINFORCED
COMPOSITE FIBERS

Prepared by
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Office of Metals, Minerals, and Commodities

International Trade Administration
U.S. Department of Commerce

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Abstract

This study, completed in September 1985, deals primarily with carbon and aramid fibers. Because of their strength and light weight, these fibers are being used to an increasing extent in advanced composite materials. The greatest demand for advanced composite materials containing carbon fibers comes from the aerospace industry; those containing aramid fibers are used chiefly to reinforce rubber products, particularly tires.

There are eight manufacturers of carbon fibers in the United States, and virtually all of them use the precursor polyacrylonitrile (PAN). While all but one company import their PAN needs, they are now developing their own domestic precursor supply. The estimated value of U.S. carbon fibers shipments was \$75 million in 1984. U.S. capacity to produce carbon fibers exceeds demand by a wide margin.

The world aramid fiber industry is dominated by DuPont's Kevlar. Foreign companies are now developing aramid production capacities to compete with Kevlar, and DuPont has filed several patent infringement suits. Competition in the aramid fiber market will stiffen once Dupont's patents end in the early 1990s. At present, DuPont's supply capabilities far exceed world demand.

The principal foreign producers of carbon fibers are Japan and the United Kingdom. In addition, France, West Germany, and Israel have some production capacity.

Present U.S. leadership in prepreg and fabrication technology is expected to continue, with domestic producers serving as the major suppliers to the U.S. aerospace industry. Domestic carbon fiber producers will also continue as the major supplier to the U.S. aerospace industry. However, carbon fibers are subject to intense competition, particularly from the Japanese, who are trying to develop high-quality, low-cost fiber from pitch. Although the U.S. possesses the world's largest fabricating capacity and is the world's leading producer of composite reinforced materials, it is dependent on imports for most of its raw material supply. Thus, its leadership position is not necessarily assured over the long run.

The study identifies a number of options which the U.S. Government might consider to support production of these fibers, including: (1) better data collection; (2) supporting more work in advanced materials by providing for more fellowships and research for the study of composite materials; and (3) review the nation's requirements for these materials during an emergency and utilize, if necessary, the Defense Production Act to ensure that supplies are adequate to meet these needs.

FOREWORD

This assessment looks at certain reinforcement composite materials. Particular attention is given to the carbon fiber industry and to aramid fiber which has only one domestic production source. Also examined, are boron, alumina, silicon carbide, and silica and quartz fibers. For the most part, there is very little statistical data available regarding production, shipments, uses, and imports and exports concerning these materials due to the proprietary nature of the processes and because many are in their research and development stage. Furthermore, much of the Research and Development funding has been provided by Department of Defense for military applications. Data regarding most of these projects are very limited.

A number of individuals and organizations both private and government contributed to this assessment by providing technical advice, data and information sources. These organizations include the Bureau of Mines, Department of Defense, Offices of the International Trade Administration, Hercules Inc., Union Carbide Corp., DuPont Inc., and the Georgia Institute of Technology. However, by far, the primary data source for this report was a number of recent studies completed for the Institute for Defense Analyses by Dr. Stanley L. Channon. The assistance provided by Dr. Channon and others is gratefully acknowledged.

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Except where indicated, sources for Tables and figures presented are from several studies completed for the Institute for Defense Analyses by Dr. Stanley L. Channon.

COMPOSITE REINFORCEMENT MATERIALS

Executive Summary

This competitive assessment deals with fibers--chiefly carbon fibers and aramid fibers--which are increasingly being used for various purposes in advanced composite materials. Embedded in a matrix, such a polymer or rubber, carbon and aramid fibers improve the strength, stiffness, or durability of the composite material. They can also be used to impart other characteristics to the composite material, such as better electrical conductivity or greater wear resistance.

Carbon and aramid fibers have another valuable characteristic, and that is their light weight. Because they add strength or stiffness or some other desired quality to a material while reducing weight, carbon fibers are now used for some military purposes, and it seems likely that more military uses will be found for them. At the moment, however, the greatest demand for advanced composite materials containing carbon fibers comes from the aerospace industry. Sports equipment manufacturers, principally in the Far East, also have found a number of different uses for carbon fibers, incorporating them into such things as tennis racket frames and golf clubs. Aramid fibers are used chiefly to reinforce rubber products, particularly tires. The other fibers briefly discussed in the report--boron, silica, and so on--are produced in much smaller quantities, and except for boron fibers, have only been used experimentally.

Very little "hard" statistical data regarding production, shipments, uses, imports and exports are available covering these materials due to the research and development being conducted on them and because of the proprietary nature of the processes. Much of the R and D funding has been provided by DOD for military applications. Data regarding many of these projects are limited. Individual company production, capacity, and end-use data for such fibers as boron, alumina, silicon carbide fibers and whiskers, and silica and quartz fibers are proprietary. In fact, they are non-existent as an individual fiber industry statistics. The major aramid fiber, Kevlar, is a DuPont patented product. DuPont considers much of the data regarding Kevlar to be proprietary.

The carbon/graphite fibers industry, with an estimated value of shipments of \$75 million dollars in 1984, also treats most of its data as proprietary. At present, data reported by the Bureau of the Census (Census of Manufacturers, Annual Survey, etc.) are included in basket categories. Trade data (imports/exports) for these materials are also reported in basket categories. The Bureau of Mines Minerals Yearbook reports quantity and estimated value of U.S. production of graphite fibers .

Domestic Carbon Fiber and Aramid Fiber Producers

There are eight manufacturers of carbon fiber in the United States, the best-known being such large firms as Hercules, Union Carbide, and Celanese. With few exceptions, all eight manufacturers make their carbon fibers from the precursor polyacrylonitrile (PAN). All but one of the U.S. makers import the PAN they need from either Japan or the United Kingdom. Total U.S. production capability of carbon fiber amounted to about 4.0 million pounds annually in 1984. This figure has remained relatively unchanged over the last several years.

The only domestic manufacturer of aramid fiber is the DuPont Company. DuPont's aramid fiber is widely sold under the registered trade name Kevlar to other companies in both the United States and abroad. DuPont currently has the ability to produce about 45 million pounds of Kevlar annually.

Demand for Domestically Produced Carbon Fibers and Aramid Fibers

Current demand for U.S.-made carbon fibers is hard to ascertain precisely, but it seems clear that supply capabilities clearly outstrip demand. In 1983, U.S. producers shipped an estimated 1.85 million pounds of carbon fiber to both domestic and foreign users valued at about \$75 million dollars. It has been estimated that demand for U.S.-made carbon fibers would reach about 3 million pounds in 1985, again well below the domestic supply capability of 4.0 million pounds.

A similar situation prevails with respect to DuPont's aramid fiber, Kevlar. In 1982, DuPont sold about 17 million pounds of Kevlar to firms both here and abroad, well below its supply capability. Estimated demand for 1985 was about 23 million pounds.

Boron fibers are also sold commercially, and here again, supply easily exceeds demand. While U.S. boron fiber producers were capable of producing 50,000 pounds of boron fiber annually in 1984, demand was less than half that figure. As a result, one of the two U.S. manufacturers of boron fiber recently withdrew from the field.

Overseas Carbon Fiber and Aramid Fiber Producers

The principal foreign producer of carbon fibers is Japan. There were six Japanese companies making carbon fibers in 1984, and their total production capability amounted to about 5.5 million pounds annually. Japanese consumption for that year was about 1.3 million pounds. Japanese carbon fibers are made primarily from PAN, but some Japanese firms are making

strenuous efforts to make greater use of lower-priced pitch as a precursor for carbon fibers.

The chief European producer of carbon fibers is the United Kingdom. There, two companies (Hysol/Grafil and R. K. Carbon Fibers) have a total production capability of about 1.1 million pounds annually. France and West Germany currently produce small amounts of carbon fibers, but there are firms in both countries that are planning to increase carbon fiber production. In the Middle East, Israel has a carbon fiber production capability of 200,000 pounds a year. The European producers of carbon fiber, like the producer in Israel, use PAN as the precursor for their carbon fiber.

Overseas production of aramid fibers is currently negligible, but that situation may not last indefinitely. Firms in both the Netherlands and West Germany are planning to produce aramid fibers on a large scale. Whether they succeed in doing so will depend in large measure on the outcome of patent infringement suits filed by DuPont against the Dutch and West German firms on grounds that their aramid fibers are chemically indistinguishable from Kevlar.

Current Competitiveness

Present U.S. leadership in prepreg and fabrication technology is expected to maintain domestic exports of carbon fibers and the reexport of foreign-produced carbon fiber. Overseas operations of American companies, either as wholly-owned subsidiaries or as joint ventures, are a major factor in the foreign prepreg business. However, carbon fibers are produced around the world and subject to competition in price, quality, and dependability of supply. Furthermore, while the U.S. possesses the world's largest fabricating capacity and is the world's leading producer of composite reinforced materials, it is dependent on foreign suppliers for most of its raw materials for the manufacture of composites. Domestic carbon fiber producers will continue as the major supplier to the U.S. aerospace industry, both to civilian and growing military aerospace uses. The aerospace industry is the major user of carbon fibers and is expected to remain the major user in the foreseeable future. While the U.S. carbon fiber industry is healthy and can be expected to grow, increased competition can be expected, particularly from the Japanese who are trying to develop high-quality, low-cost fiber from pitch.

The world aramid fiber industry is dominated by DuPont's Kevlar. While foreign companies are now developing aramid production capacities to compete with Kevlar, DuPont has filed patent infringement suits against several of these companies. Competition for the aramid fiber market will stiffen once DuPont's patents end in the early 1990s.

Potential Demand for Carbon Fibers

Various estimates have been made of future demand for carbon fibers. A survey conducted by SRI International for the Department of Commerce in 1984 showed that carbon fiber demand worldwide would rise from about 3.9 million pounds in 1984 to about nine million pounds in 1987. As of 1984, however, worldwide capacity exceeded 10 million pounds, and by 1987 world carbon fiber production capability may be 15 million pounds or more.

Nonetheless, demand for carbon fiber should show a healthy increase over the next 3 to 5 years, partly because of increased demand for advanced composites from military, aerospace, and sport equipment manufacturers, and partly because of exploration of other potential uses of carbon fibers. Carbon fibers, may potentially turn up in advanced composite materials, in agricultural equipment, and in medical prostheses and implants. In each case, the high strength-to-weight ratio of carbon fibers may make it possible to manufacture products that are both lighter in weight and longer lasting than the products currently made out of more basic materials, such as steel.

Current prices of carbon fibers vary widely, from \$20 to \$300 per pound. Estimates of the size of the industry or market are premature. But a rough estimate is that the world-wide size of the market is currently about \$200 million a year and will grow to about \$500 million a year by 1990.

Meanwhile, aramid fibers are steadily coming into greater use in composite materials intended to replace the asbestos in automobile parts (brake linings and clutch facings). This demand for aramid fibers is driven by the fact that asbestos fibers have been shown to be a potential hazard to human health. Demand for aramid fibers in composite bulletproof materials is increasing.

Future Competitiveness

Between now and 1990, and beyond, it seems clear that the United States and Japan will be the principal competitors in

the production and marketing of carbon fibers. While current Japanese production capability exceeds that of U.S. firms, the American companies run a strong second in production capability and should continue to hold their dominant share of the U.S. domestic market, particularly the aerospace market. Maintaining cost competitiveness to compete with fibers from other countries with cost advantages such as low labor costs, as well as with alternate materials, will be the key to the future growth of the U.S. carbon fibers industry.

The Japanese, on the other hand, will continue to be the strongest competitor in sales of carbon fibers to final users in such Far Eastern countries as Taiwan, a country heavily involved in the production of sports equipment utilizing advanced composite materials.

In Europe, plans for large-scale production of carbon fiber in both France and West Germany suggest that both U.S. and Japanese producers of carbon fiber will encounter stiffer competition in the European market during the 1990s.

The United States--or more specifically, DuPont--can be expected to retain its dominance in the production and sale of aramid fibers. The outcome of pending law suits, however, may modify the extent of that dominance. Akzo in the Netherlands eventually hopes to produce 11 million pounds annually of its aramid fiber, registered under the name Twaron, while West Germany's Enka intends to expand its aramid fiber production from 200,000 pounds to 10 million pounds annually.

No serious threat to U.S. dominance in the production of boron fibers is expected.

Implications and Government Policy Options

The United States overshadows the rest of the world in the development and application of composite materials utilizing fibers, particularly composites used in aerospace structures. The U.S. lead, however, could be jeopardized through the transfer of composite material technology, or, in some cases, composite materials themselves. Given current and potential military applications in particular, a review of current controls on the transfer of composite materials and technology to foreign countries might be appropriate.

A review of U.S. mobilization needs could be conducted to determine if the raw materials used to produce fibers (such as PAN) should be included in the strategic stockpile.

In addition, consideration could be given to devoting greater effort to collecting data on the production, consumption, and costs of advanced composite materials that incorporate carbon, aramid, or other types of fibers. Lack of firm data of these kinds currently makes it difficult to assess competition in this emerging technology.

Lastly, to ease what appears to be a lack of sufficient educational facilities for developing materials scientists and engineers, the National Science Foundation, the Department of Education and other Federal agencies might increase their fellowships, research, and curriculum development activities with U.S. universities in the fields of advanced composite materials.

Composite Reinforcement Materials

I. Introduction

Composites are a class of materials with unique characteristics that differentiate them from monolithic materials. Because it is possible to tailor the properties of composite materials, these materials are now used to enhance the structural efficiency or other properties of a wide range of products. Although composite materials of various kinds, such as fiberglass have been available for many years, recent advances in technology have led to the development of new composite materials and associated manufacturing techniques, as well as new applications of a sophisticated nature.

New, high-performance fibers are the type of reinforcement used most frequently in today's "advanced composites." These fibers, made of such materials as carbon, aramid, boron, and silicon carbide, are incorporated within a matrix material to improve strength, stiffness, or other properties. The matrix is often a polymer, but other materials, such as metals and ceramics, are used as well. Along with fibers, so-called "whiskers" (i.e., thin hairlike crystals) and "particles" are also used as reinforcement materials. Because of their short and irregular reinforcement geometry they are more commonly used in metal matrix composites which can be fabricated by conventional metal working techniques. This paper devotes most of its attention to carbon and aramid fibers, the fibers in greatest demand today.

Advanced composite materials are found mainly in military equipment, in civilian and military aircraft and in sports equipment. In the United States, both the Federal Government and private industry have made substantial investments in research and development of advanced composite materials and in facilities for testing and manufacturing these materials. Other countries have also recognized the potential importance of advanced composites and have made investments in composite materials, in many cases drawing upon the expertise and technology of the United States.

The Advantages of Advanced Composites

Advanced composites are often used because they are "cost-effective." While the cost of an advanced composite material may be higher than the cost of alternative materials, its use results in a product with superior capabilities. The superior capability may be improved performance, or reduced operating costs (fuel, maintenance, etc.).

Advanced composites are also used in certain circumstances because they are "cost competitive;" i.e. in situations where total manufacturing costs will be less if advanced composites are used in place of other materials. These are situations where the use of an advanced composite material instead of a more conventional material reduces design, tooling, or labor costs by a sufficient margin to more than offset the higher cost of the advanced composite material.

One major attribute of advanced composite materials is that using them results in optimum mechanical performance in relation to structural weight, resulting in either minimum weight for a given level of performance or maximum performance at a given weight.

Often, the use of advanced composites means additional freedom in product design, resulting in more efficient use of materials, more functional system geometry, or reductions in manufacturing costs.

Advanced composites have other special characteristics that enhance their value for specialized applications, particularly in military equipment. These characteristics include corrosion resistance, thermal stability, abrasiveness, and various electrical properties.

A major force behind the substitution of advanced composite materials for metals is that advanced composites weigh significantly less. The energy requirements, payload, and operating costs of any type of transportation vehicle are normally a function of structural weight, whether the vehicle is a bicycle, an automobile, or a spacecraft. A reduction in structural weight can therefore mean an increased payload, greater range, better performance in terms of speed and acceleration, or greater fuel economy. Weight is also likely to be a crucial factor when some type of equipment must be transported to a remote location that can only be reached by aircraft or space vehicle.

A similar principle applies to various classes of equipment whose ease of operation depends on physical strength. Better control and ease of handling, and thus improved performance, are the chief reasons for the use of advanced composites in sports equipment and medical prostheses.

The speed, and hence the productivity, of various reciprocating, oscillating, and rotating machinery is determined to a large degree by the inertia and fatigue resistance of critical moving parts. The productivity of these machines is sometimes improved significantly if composite materials are used for these critical parts.

Advanced composites can sometimes provide another weight-related advantage. Since the composite component is lighter in weight, the supporting structure does not have to be as massive and the weight of other structural elements can be reduced. Thus, depending on the specific system, reducing the weight of a component by one pound may lead to a reduction in total system weight of two or three pounds.

Fiber Technologies

Carbon Fiber Technology

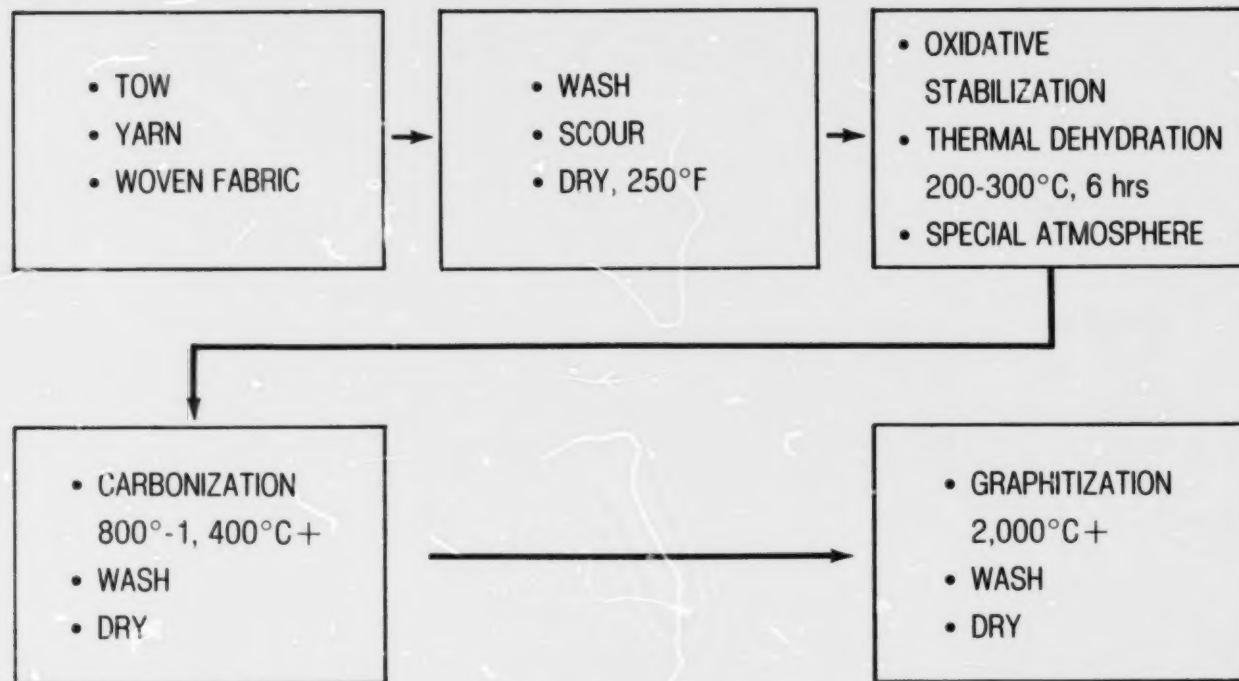
The technology involved in the production of carbon fibers is actually several technologies, each with its own unique problems. Although any carbon-containing material can be converted into a carbonaceous fiber, each precursor material behaves in a different manner during the pyrolysis necessary to produce the fibers, depending upon its chemistry, physical form, and processing conditions. For example, rayon fibers (which are derived from regenerated cellulose fibers) are characterized by short cross-linked microfibrils which are randomly oriented and which must be removed by special treatment before tension is applied during pyrolysis. On the other hand, carbon fibers derived from polyacrylonitrile (PAN) exhibit a fibril backbone of carbon atoms which can be stretched in the earlier stages of stabilization and pyrolysis. PAN precursor is derived from special treatment of acrylonitrile in the polymerization and spinning stages. When pitch is the precursor used to produce carbon fibers, the micro-crystalline alignment is achieved through the formation of a liquid crystalline mesophase in the pitch, which is then spun into fibers and processed by oxidation stabilization and carbonization to produce the necessary orientation in the fiber structure.

For each of these three precursor materials, the processing required to ensure the necessary characteristics in the precursor also involves some critical technology. Rayon technology is available worldwide. PAN technology is available in the United States, the United Kingdom, Japan, Germany, and the USSR, although production of PAN fibers is centered in the United Kingdom and Japan. Pitch is a potentially lower-cost precursor, but widespread use of pitch as a precursor is hampered by certain chemical difficulties that make it difficult to ensure fiber consistency. The United States and Japan are currently making the strongest efforts to improve the technology used to produce carbon fibers from pitch.

A schematic diagram of the key steps in producing carbon fibers is shown in Figure 1. Each of these steps requires specialized equipment, handling facilities, and environmental controls. The details of these operations are proprietary to the fiber manufacturers. Specialized equipment, such as carbonizing and graphitizing furnaces, handling mechanisms, and fiber-spooling devices are frequently developed by fiber manufacturers in the course of developing new or improved fibers.

FIGURE 1

Manufacturing Process for Fibrous Carbons and Graphites



Source: Institute for Defense Analyses

The physical and surface characteristics of a fiber are critical to the behavior of a composite material in which the fiber is utilized. Much attention is paid to these characteristics, especially surface condition, which is often essential to the success of the composite.

Aramid Fibers (Kevlar) Technology

Aramid fiber is a synthetic organic fiber produced in the United States by DuPont under the registered trade name "Kevlar." Kevlar is the subject of several DuPont patents which describe certain aspects of the total manufacturing process, but the manufacturing details themselves are proprietary. The basic chemistry involves the polymerization of p-aminobenzoylchloride in the presence of N, N dimethyltriaminophosphate to produce poly p-benzimide. This is then spun at temperatures above 500 degrees F. to form continuous filament yarns, staple fiber for conversion to spun yarn, short cut fiber, and pulp (ground fiber). Aramid fiber is distinguished from other organic chemical fibers by its extremely high tensile strength and modulus. This tensile strength and modulus, combined with very low density, give aramid fibers extremely useful properties in situations where weight and strength are critical. On an equal weight basis, aramid fiber is more than twice as strong as the strongest industrial nylon and polyester yarns, 1.5 times as strong as "E" type fiberglass, five times as strong as steel, and ten times as strong as aluminum, according to DuPont. Kevlar is also flame-resistant and non-melting, and it is resistant to most common chemicals except for strong acids and bases.

The technology for manufacturing aramid fiber is also known in Europe, the Soviet Union, and the People's Republic of China. In fact, a rather complete treatise on the chemistry of aramid-type materials has been published in the USSR.

Boron Fiber Technology

The basic process for producing boron filaments involves the decomposition of boron trichloride by hydrogen and the deposition of boron on the surface of the resistance-heated (1300°C) substrate filament (tungsten or carbon) in a closed chamber. The filament is passed through the glass chamber, and electrical contact is accomplished by means of mercury-filled electrodes. The diameter of the fiber is determined primarily by its rate of travel through the chamber. The quality of the substrate material is critical to the uniformity of the boron filament; slight variations in substrate diameter result in increased local resistivity and hot spots, which affect the

rate of reaction between the boron trichloride and the hydrogen. Since each fiber is produced in a separate chamber, the typical production facility consists of numerous chambers, pay-off and take-up reels, electrical connections, gas flow controls, etc. The complexity of this type of facility contributes to the high cost of boron fibers.

Tungsten has been found to be very suitable as a substrate because of its high melting point and high strength at the elevated temperatures necessary for the boron deposition process. In certain applications, however, tungsten's high density (and high atomic number) are drawbacks.

Carbon is also attractive as a substrate. The cost is lower, the rate of deposition can be as much as 30 percent higher, the density of the fiber is lower even though the stiffness is the same, and carbon's lower atomic number makes it useful in some nuclear applications.

Alumina Fiber Technology

Alumina fiber is also made by a DuPont proprietary process. The surface of the spun fiber shows the typical cobblestone appearance of glass-free polycrystalline alumina.

The fibers are often supplied in tape form in a fugitive acrylic binder, which makes it possible to handle the tape until it can be impregnated with a matrix material. The fugitive binder is then removed by thermally treating the fibers at temperatures of about 500°C.

Silicon Carbide Fiber and Whisker Technology

The basic process for producing silicon carbide fibers is identical to that used to make boron fibers, except that the source of the silicon carbon fiber is methylchlorosilane rather than boron trichloride. The decomposition of the methylchlorosilane takes place on the surface of the heated substrate filament (tungsten or carbon), and silicon carbide is deposited on the surface of the fiber as it progresses through the reaction chamber. The deposition rates for silicon carbide are higher than for boron. Methylchlorosilane is inexpensive and readily available. Details of the process are considered proprietary by the two U.S. producers, AVCO and Composite Technology, Inc., although silicon carbide filaments were originally developed by General Technology Corporation in 1966 under contract to the U.S. Air Force. Silicon carbide fibers are also produced without a substrate by pyrolysis of polycarbosilane, using a process developed in Japan.

Whisker technology was initiated in the 1960s, but interest declined because of the high cost of whiskers and the relatively small fractions of whisker material in the products. The silicon carbide whiskers are produced in the United States by pyrolysis of rice hulls, which naturally contain silicon and carbon. The product consists of only 15 percent to 20 percent silicon carbide whiskers, which must be processed to reduce the powder fraction. In recent years, ARCO has improved the process for manufacturing silicon carbide whiskers. Silicon carbide particles with properties similar to those of whiskers are also used as reinforcement materials.

Since the mid-1960s, more than 30 patents pertaining to silicon carbide fibers and whiskers have been issued to U.S., French, British, Dutch, German, and Japanese assignees. There has also been considerable research and development in the USSR. Despite these efforts, silicon carbide fibers have not found wide practical uses, primarily because of their cost.

Silica and Quartz Fiber Technology

Silica and quartz fiber technology is well-known, and silica fibers are produced in many countries. Quartz fibers are produced from a high grade of quartz mined in Brazil and processed in France.

II. A General Description of the Industry

Composite materials are supplied by large diversified organizations--chemical, petrochemical or carbon companies. Table 9 estimates carbon fiber production capacity by country and firm. Since most composite reinforcement materials have petrochemical origins, any country which has access to these basic materials and the necessary technology can become self-sufficient in composite reinforcement materials production. There are many joint international ventures in the composites industry, and a summary of these interrelationships is shown in Tables 1 and 2. In the United States, which is the world's leading producer of boron and aramid fibers as well as the leading source of "prepreg"^{1/} materials, the major producers of the reinforcement materials used in composites are: DuPont, Hercules, Celanese, and Union Carbide. Many foreign countries in which fabrication is performed rely on the U.S. for prepreg materials.

^{1/} "Prepreg" is a term commonly used in the composites industry to describe the intermediate product consisting of reinforcements containing thermoplastic resins or partially cured thermosetting resins.

TABLE 1.

INTERNATIONAL INTERRELATIONSHIPS, CARBON FIBER AND PRECURSOR

Country	Company	Relationship
United Kingdom	Hysol/Grafil	Plant using Courtaulds precursor ships precursor to some U.S. carbon producers.
	RK Carbon Fibers	Considering plants in Israel and Spain, would consider U.S. plant, if justified.
France	SOFICAR	Joint venture, Toray, Elf Aquitaine and Pechiney will use Toray precursor at start.
	Serafim	will shut down carbon fiber plant when above plant operating.
	Rhone Poulenc	PAN precursor plant shut down.
Germany	SIGRI	Owens Polycarbon in California. Precursor for large tow may be from Courtaulds. May be working with Kureha pitch. Buying C fiber from Toho. Relationship with Hoechst for textilegrade PAN.
	ENKA	Joint venture plan with Toho and Celanese for carbon fiber plant using Toho precursor.
Japan	Toray	Licensed precursor and carbon process to UCC. Joint venture with Elf France. Joint venture with Bristol Composites, U.K.
	Toho	Represented by Celanese in the U.S. Joint venture with Enka and Celanese in Europe.
	Kureha	Possible arrangement with SIGRI.
	Sumitomo	Joint venture with Hercules for PAN precursor plant in Japan. Possible installation of plant in U.S.
	Mitsubishi	Uses process for carbon fiber developed at HITCO.
United States	Hercules	Pan precursor for Sumika- Hercules, Japan and Courtaulds, U.K.
	Union Carbide	Plant for PAN precursor and carbon fiber based on Toray technology. Markets Toray carbon fiber also.
	Celanese	Plant for carbon fiber using Toho-Beslon precursor. Markets Toho fiber also. Joint venture plan with Enka and Toho.
	Dexter/Hysol	Plant for carbon fiber in U.S. using Courtaulds.

SOURCE: Institute for Defense Analyses

Table 2. INTERNATIONAL INTERRELATIONSHIPS; RESINS AND PREPREGS.

Country	Company	Relationship
United Kingdom	Ciba-Geigy	Division of Ciba-Geigy, Switzerland. Joint Venture with Asahi Chemical Co., Japan
	Fothergill & Harvey	Teamed with American Cyanamid to form Cyanamid Fothergill.
	I.C.I	Branches worldwide.
Switzerland	Ciba-Geigy	Plants in U.K., U.S., and other countries. Part owner of Brocher.
France	Brochier	Part owned by Ciba-Geigy, Switzerland.
	Rhone-Poulenc	Bismaleimide (Kerimid) source to U.S. Made PAN but discontinued.
	Roussel	Source of DDE marketed through Ciba-Geigy (U.S.).
	Clf Chimie	Source of some resins.
	Stevens-Genin	Became 50% Stevens, 50% Hexcel 2 years ago.
Belgium	Narmco	Distributor of Narmco (U.S.) products in Europe.
	Hexcel	Distributor of Hexcel (U.S.) products in Europe.
Israel	?	Using price-supported prepreg from U.S. suppliers. Considering own prepreg plant.
Japan	Kasell-Fiberite	Joint venture of Mitsubishi Chemical Co. and Fiberite Corp. (U.S.).
	Asahi Composites	Joint venture of Asahi Chemical Co. and Ciba-Geigy (U.K.).
United States	Hysol/Hysol	Joint venture with Courtaulds.
	Ciba-Geigy	plants in Switzerland, U.K., Japan, etc.
	Narmco	Distribute in Europe; Division of Celanese
	Hexcel	Distribute in Europe, Japan, etc.
	Fiberite	Distribute in Europe, Japan; joint venture with Mitsubishi Chemical, Japan.
Germany	Technochimie	Bismaleimide source to U.S. prepeggers
	SIGRI	Prepreg fiber from Toho.
	Bakelite	Possible source of DDE for Europe.
Italy		Purchase from U.K. or U.S. (Fiberite, Hexcel, Narmco). May produce locally (ANIC/Hercules).
Spain		Purchase from U.K. or U.S.
Holland		Purchase from U.K. or U.S.
Scandinavian Group		?

SOURCE: Institute for Defense Analyses

Many of the producers of carbon fibers have adopted a strategy of selling them in all of the major market areas--the Far East, the United States, and Europe. Marketing agreements often involve the exchange of both materials and technology, which is illustrated diagrammatically in Figure 2 for PAN-base carbon fibers. Similar exchanges exist among various prepreg producers. Some of these ventures allow companies with complementary capabilities-- e.g., Fiberite (prepreg) and Mitsubishi (carbon fiber and precursor)--to strengthen their overall competitive position. There are also several international ventures involving the fabrication of composite products, both semi-finished and finished.

The establishment of these ventures is due, in part, to a trend in each of the consuming countries toward self-sufficiency in materials. In many cases, manufacturers who wish to sell materials to their government--especially materials for military applications--must be able to demonstrate that the materials are available from local sources. It can be argued that internationalization has made composite materials more widely available and has spurred the development of new applications for composite materials in foreign countries. This may result in an increase in the production of composites in countries where labor rates are lower than they are in the United States, and may, in the longer term, make it more difficult for U.S. producers to compete in the world market.

In Japan, the leading producers of PAN-based carbon fibers are four chemical companies whose major business is the production of textile fibers. Much of the PAN produced by Japanese companies is exported to the United States, Europe, and countries in the Far East. The Japanese companies moved into large-scale production of PAN-based fibers as a way of using their excess acrylic fiber capacity. This early jump into fiber production has resulted in Japanese dominance of this market. The carbon fiber technology used in Japan, however, has been imported into the United States by Union Carbide and Celanese Corporation, and is being transferred to France through a joint venture between the leading Japanese producer, Toray, and the French organizations, Societe Nationale Elf Aquitaine and Pechiney. Another joint venture involving Enka in West Germany, Toho-Beslon in Japan, and the Celanese Corporation is in the planning stage. Foreign companies like Toho-Beslon and Sumika-Hercules in Japan and Courtaulds in the United Kingdom currently supply 70 percent of the PAN precursor used by U.S. manufacturers of carbon fibers.

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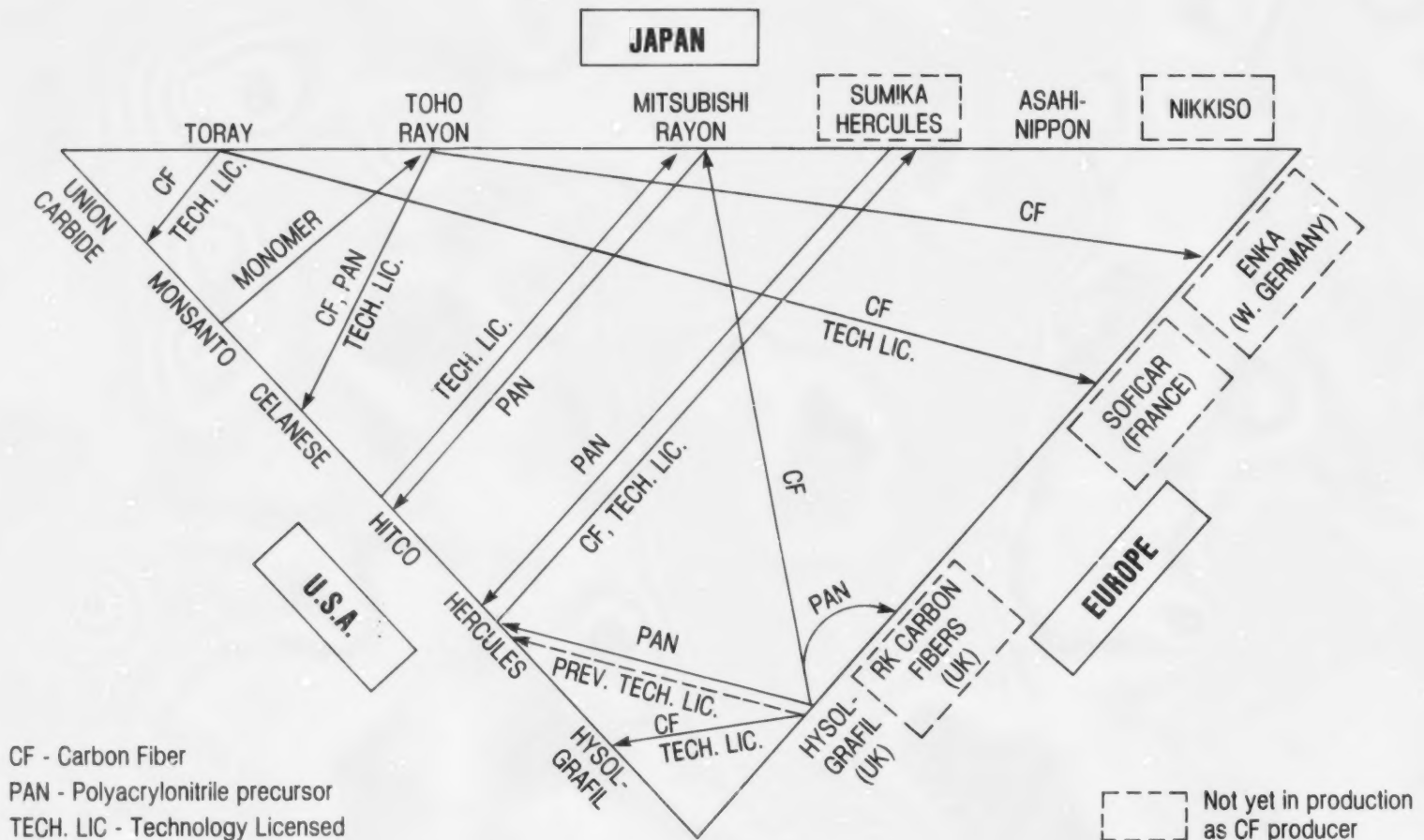
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FIGURE 2

Pan-Base Carbon Fiber Organizations, Worldwide Relationships

(Basic chart provided by Toray, extended by S. L. Channon.)



Source: Institute for Defense Analyses

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Fiber Production in the United States

Although the United States has the world's largest fabricating capacity and is the world's leading producer of composite reinforced materials, it is dependent on foreign suppliers for most of the raw materials used to manufacture composites, including fibers.

Until recently, the United States was completely dependent on Japan and the United Kingdom for carbon fiber derived from PAN. However, foreign-made PAN is now being used in the United States by several companies to produce carbon fibers. Only, one U.S. maker of carbon fibers, Union Carbide Corp., uses domestic PAN precursor.

The U.S. chemical and petrochemical industries do not produce the materials used in composites to the same extent as the Japanese. On the other hand, the United States has developed strong capabilities in the production of prepreg materials and fabrication techniques involving both prepreps and the impregnation of dry fibers. The United States is also a leader in the design and application of composites, particularly in military systems and commercial aerospace vehicles. There are several programs of research and development directed toward making more extensive use of composite reinforcement materials as primary structural materials in aerospace vehicles and applications.

Carbon Fibers

In 1982, U.S. production capacity for carbon fibers from all three types of precursor (PAN, pitch, rayon) amounted to an estimated 4.7 million pounds (see Table 3). Domestic demand for carbon fiber in 1982, on the other hand, was estimated to be 1.1 million pounds, meaning that carbon fiber production capability far exceeded demand. Domestic demand for carbon fiber was projected to grow to about 2.3 million pounds by the end of 1986. (Other projections of future demand will be shown later in Tables 10, 11, and 12.)

PAN-based carbon fibers accounted for nearly 3 million pounds of capacity, making polyacrylonitrile by far the most commonly used precursor. Capacity to produce carbon fibers from pitch amounted to about 1 million pounds, while rayon-based carbon fiber production capacity amounted to about 758,000 pounds.

There are eight domestic producers of PAN-based carbon fibers, all but one of which import the PAN they use from textile companies in Japan or the United Kingdom. The sole domestic producer of carbonizable PAN is Union Carbide, which now supplies about 10 percent of U.S. demand for PAN.

TABLE 3. U.S. PRODUCTION SOURCES OF CARBON FIBER

Carbon/Graphite Fiber Type	Producer	Trade Name	Production Capacity ¹ 1982, lbs	Precursor Source	
				U.S.	Foreign
Rayon-Base	Polycarbon Union Carbide HITCO	— MCA CCA-4	300,000	AVTEX ² AVTEX AVTEX	
			250,000		
			208,000		
			758,000		
PAN-Base (Polyacrylonitrile)	Hercules	Magnumite	1,300,000	Du Pont or ³ Monsanto	Sunika-Hercules (Japan) Courtaulds ⁴ (U.K.)
			800,000		
	Union Carbide	Thornel-T	300,000		Toho Beslon (Japan) Courtaulds (U.K.)
			180,000		
	Celanese	Celion	150,000	Du Pont Orlon	Courtaulds (U.K.) Mitsubishi (Japan)
			200,000		
	Stackpole	Panex	50,000		Courtaulds (U.K.)
			4,000		
	AVCO	HITEX	2,904,000		
	HITCO	Fortafil			
	Great Lakes	—			
	PII	—			
Pitch-base	Union Carbide	Thornel-P	1,000,000	Ashland Allied Marathon Mobil	

¹ Capacities include new facilities reported to be in place by end of 1982.

² Some rayon precursor fiber drawn from stockpile IRC rayon, no longer produced.

³ As basic acrylonitrile commodity — not as fiber.

⁴ Original source, not currently used.

SOURCE: Institute for Defense Analyses

It is still an open question as to whether PAN from different sources is interchangeable. Both foreign and domestic producers of PAN are placing greater emphasis on improving the processing of acrylonitrile, since this is believed to be the key to more successful carbon fibers. Although the PAN required for carbon fiber production constitutes an insignificant percentage of all the acrylonitrile fiber produced for use in textiles, plant size is an important factor in the cost of PAN. Some foreign producers think that it is uneconomical to build a carbon fiber plant capable of producing only a few hundred tons of fiber a year.

Union Carbide--as mentioned earlier, the only domestic producer of PAN--is also the only domestic producer of carbon fibers from pitch. Carbon fibers based on pitch come in three grades, differentiated according to modulus.

The third precursor used to make carbon fibers is rayon, and about 5 percent of the 33 million pounds of rayon fiber currently produced in the United States eventually winds up as carbon fiber. Rayon-based carbon fibers are made domestically by three producers--Polycarbon, Union Carbide, and HITCO. All three of these producers buy their rayon from a single domestic source, namely AVTEX.

Aramid Fibers

DuPont's aramid fiber Kevlar is widely used throughout the world. Kevlar was developed in the late 1960s as an outgrowth of work on an earlier aramid fiber called Nomex. DuPont began producing a modest 300,000 pounds of Kevlar annually in 1971, and then gradually increased its production facilities to a capacity of about 15 million pounds a year in 1978. As demand increased, DuPont enlarged its production capability to the present 45 million pounds a year in 1982. Kevlar is used mainly for tire cord reinforcement and cordage. It is also used, to a much lesser degree, for structural reinforcement in such things as aircraft and space hardware. Demand is currently estimated at about 17 million pounds.

Boron Fibers

Boron fibers are produced primarily in the United States. Current production is estimated at about 50,000 pounds annually. Estimated consumption of boron fibers in 1982 was about 14,000 pounds, and was expected to be about 28,000 pounds by 1985. Since both current and projected demand are much smaller than current supply capacity, one of the two domestic suppliers recently discontinued production.

Alumina

DuPont is the only U.S. producer of alumina fibers. Production is limited to the present needs of research and development programs and could be expanded. The fibers are made from domestic raw materials provided by aluminum manufacturers.

Silicon

Silicon carbide fibers are produced by two domestic companies, AVCO and Composite Technology, Inc. Production is estimated at about 500 pounds per year, which is used for experimental programs. Another company, Dow Corning, plans to market silicon carbide fibers produced by Nippon Carbon of Japan. Another U.S. company, ARCO, produces silicon carbide whiskers.

Silica

One producer in the United States, Owens-Corning, furnishes S glass and S-2 glass, although S-glass is being discontinued in favor of S-2 glass. Silica fibers are available in sufficient quantity domestically to satisfy current domestic demand. Quartz fibers produced in France and imported into the United States satisfy current U.S. demands, but the United States has domestic sources of the raw material used to produce the fiber that could be exploited if necessary.

Fiber Prices

The price of carbon fibers vary due to differences in grade and use. Because carbon fibers made from PAN have greater strength than fibers made from pitch, they are more expensive than pitch-base carbon fibers used mainly for commercial products. All carbon fiber prices have declined in recent years as a result of rising production. During the early 1970s, prices were in the \$150-\$300 per pound range. By 1984, prices had declined to the \$20-\$300 per pound range, with most fibers selling at the low end of the price range.

The price of Kevlar is now in the \$5-\$10 per pound range although the price of some specialty types goes up to \$30 per pound. DuPont's recent expansion in capacity should mean stable prices for Kevlar in the near future.

The prices of the other reinforcement fibers are not particularly meaningful, due to the absence of normal supply/demand conditions. For the most part, these materials are in the research and development stage and have very limited commercial applications. Government financial input towards R&D projects has been an important element in their development.

Cost data related to the production of these materials is not available because of the proprietary nature of the production processes. But it is evident that costs have declined as producers have developed more efficient production processes and as commercial or military uses for them have been found. In many instances, current costs bear little relationship to what the future costs would be at commercial production levels.

III. Foreign Producers of Advanced Composite Reinforcement Materials

The composite reinforcement materials industry is an international one. Since some operations are performed primarily or solely in certain countries, the consequence is international interdependence. Table 4 summarizes the major activities in each segment of the industry in various countries. Japan and the United Kingdom are the primary sources of PAN, for example, while France is the sole source of diaminodiphenylsulfone (DDS), a resin hardener. The United States, on the other hand, has been the principal supplier of prepreg to fabricators around the world. In other words, there is very little of the vertical integration from raw material to fabricated item that is found in the metals industry. During the past few years, however, there has been a trend towards self-sufficiency in composite reinforcement materials in several countries. As shown in Tables 1 and 2, there are many joint international ventures in the industry.

Advanced composite reinforcement materials are utilized by foreign fabricators in aerospace materials, sporting goods, and general industrial products. Fabrication of aerospace products is often done for other countries, as in the case of Japan, which uses mostly glass and aramid reinforcement materials. The sporting goods industry in Japan is large and growing rapidly, and it is estimated that about 80 percent of all PAN-base carbon fiber produced in Japan is used for sports equipment. The use of carbon fibers in sporting goods products in South Korea, Taiwan, and other Far East countries is also growing rapidly. Japanese PAN-base carbon fiber producers are substantial suppliers to those countries.

In France, advanced composite reinforcement materials are used by Aerospatiale, the national aerospace company. In Israel, PAN-base fibers are now used as a replacement for asbestos in structural applications, and future plans indicate a move toward aerospace applications. Italian development of advanced composite reinforcements is aimed at the state-owned aerospace industry. The move in Italy towards development of composite materials for the aerospace industry is similar to what is

**TABLE 4. INTERNATIONAL COMPOSITES INDUSTRY
PRODUCTION OF ADVANCED ORGANIC MATRIX COMPOSITES**

Country	Major Activity in Industry Segment											
	Carbon Precursor Fiber ⁽¹⁾	Structural Fiber							Resin	Hard- ener	Pre- preg	Fabri- cation
		Carbon	Boron	Glass	Aramid	SiC	Quartz	Al ₂ O ₃				
<u>North America</u>												
United States	XX	XXX	XX	X(S)	XXX	X		X	XX	X	XXXX	XXXX X
Canada												
<u>Europe</u>												
Belgium											X	? XX
Denmark												X
France	X	X	X	X(R)			X		X	XX		X
Israel		X										X
Italy												XX
Netherlands			(X)									X
Norway												X
Spain												X
Sweden												X
Switzerland									X	X		? XX
United Kingdom	XX	XX						X	X	X	XX	X
W. Germany	X	X	X		X	X			X	X		X
<u>Asia/Pacific</u>												
Australia									X			X
China (PRC) ⁽²⁾	?	?			?				X			? X
Indonesia												X
Japan	XXX	XXX			?	XX		X	X	X	X	X
South Korea												X
Taiwan												X

(1) Includes rayon, pitch and polyacrylonitrile

(2) Reportedly has some capability

X's indicate qualitative relative production status

(X) Latent Capability

Source: Institute for Defense Analyses

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taking place in France and the United Kingdom. The most advanced applications for composite materials in the United Kingdom are the aircraft components being developed at British Aerospace and Westland Helicopters. In West Germany, the major use for composite materials is also aerospace, particularly for helicopters. The rest of this section discusses work on advanced composite reinforcement materials on a country-by-country basis.

Japan

Japan is active in a broad spectrum of composites technology and production. It is principally noted for its carbon fiber, but it is also producing ceramic fibers, such as silicon carbide fiber in both continuous and discontinuous forms, and alumina fiber. Prepregs are available from each of the carbon fiber producers and from the Yokohama Rubber Company. The industry in Japan is strongly centered on the production of PAN-base carbon fibers, drawing upon the capacity of the Japanese petrochemical industry to produce large amounts of acrylics. However, the possibility of using coal tar pitch as a precursor for carbon fiber is now being vigorously pursued. Japan uses large quantities of coal for steelmaking and power generation and coal tar pitch is available in abundance. The Japanese steel companies, facing strong competition from steel plants in Korea and Taiwan and also visualizing composites as a future threat, have become interested in diversifying into new areas, such as production of pitch-base fiber. Mitsubishi Chemical, for example, has developed a coal tar pitch-based fiber with properties similar to PAN-base fiber.

Although the cost of the pitch itself is low, several purification steps are needed to make a suitable precursor for carbon fibers. As a result, the cost of pitch precursor is presently similar to that of PAN precursor. It is also technically more difficult to achieve high strength with pitch-base precursor. For these reasons, it is expected that PAN will continue to be the world's dominant precursor for some time.

PAN-Base Carbon Fiber. Four companies in Japan (Toray, Toho-Beslon, Mitsubishi Rayon, and Asahi-Nippon) produce PAN-base carbon fibers in a variety of tow sizes, ranging from 3,000 to 12,000 filaments. Sumika-Hercules, which is now a supplier of PAN precursor to Hercules in the United States, is expected to become a carbon fiber producer in the future. A carbon fiber plant based on Hercules technology is now in the planning stage.

Japanese carbon fiber production capacity for 1980-1982 is summarized in Table 5, which shows a five-fold increase in PAN-base fiber capacity during that period; further growth is expected. Nearly 90 percent of the PAN-base fibers are produced by Toray and Toho-Beslon. Toray has also made commitments with Societe National Elf Aquitaine to produce fiber in France as part of a joint venture known as SOFICAR (Societe Fibre de Carbone). This joint venture is designed to produce 600 tons a year of carbon fiber. Toho-Beslon has also entered into agreement with Celanese (U.S.) and Enka (W. Germany) for the production of carbon fiber in Europe. Table 6 lists the producers of carbon fiber (PAN-base) in Japan, France, West Germany, and the United Kingdom. It also indicates capacity and precursor source.

Pitch-Base Carbon Fiber. Pitch-base carbon fiber has been produced by Kureha in Japan for several years at a rate of 240 to 300 tons a year, which is essentially its full capacity (Table 5). The company planned to increase its capacity to 3,000 tons a year by 1985. Both bottom oil from petroleum refining operations at Toyo-Menryo (a subsidiary of Exxon) and Idemitsu Oil Company, and coal tar pitch from Sumitomo Metal Company, have been used as precursor materials. Kureha does not presently produce a higher grade pitch fiber but is conducting research on pitch-base structural fiber.

Interest in pitch-base fibers in Japan has increased significantly. The production of high performance carbon fibers made from low-cost oil pitch rather than from PAN would result in major cost savings. There are now many other companies investigating both petroleum pitch and coal tar pitch as precursor sources. These include Mitsubishi Chemical, Nippon Oil-Nippon Petrochemicals, Nippon Steel-Nippon Steel Chemical, Kawasaki Steel-Kawatitsu Chemical, Mitsui Coke (with Toray), Sumitomo Metal Mining, and Asahi Glass. Mitsubishi Chemical has developed the capability to produce high grade carbon fibers from coal tar pitch with properties similar to Toray PAN-base T-300 fibers and planned to have a facility capable of producing 300 tons a year on stream by 1984-85. Nippon Carbon plans to produce 60 to 120 tons a year of pitch-base carbon fiber. A small amount of coal tar pitch-base fiber is produced by a joint Mitsui Coke and Toray venture. Other companies are still in the research stage.

Silicon Carbide Fibers and Whiskers. Continuous silicon carbide fiber is produced by Nippon Carbon Company under the trade name Nicalon. Nippon's production capability was recently expanded from 200 kg per month to 1 ton per month. The company has also improved the characteristics of the fiber by lowering its residual oxygen content. The precursor, polycarbosilane, is presently being produced by Shin-Etsu Chemical Company under a license from Nippon Carbon.

TABLE 5. JAPAN CARBON FIBER INDUSTRIES

Industry	Capacity, tons/yr		
	1980	1982	Future
Pan-Base (Polyacrylonitrile)			
Toray	240	1260	-- -- -- -- 300 (1985)
Toho Belson	240	1020	
Asahi Nippon	60	180	
Mitsubishi Rayon	0	120	
Sumika Hercules ¹	0	0	
Nikkiso ²	0	0	
	540	2580	
Pitch Base			
Kureha	240 to 300	240 to 300	3000 (1985)
Mitsubishi Chemical	-	-	300 (1984)
Nippon Carbon			60 to 120 (1983)
Mitsui Coke/Toray		0.6 to 6	
Sumitomo Metal		R&D	
Nippon Steel		R&D	
Kawasaki Steel		R&D	
Nippon Kokan Steel		R&D	
Dainippon Ink and Chemical		R&D	

¹ Supplies PAN precursor to Hercules (U.S.) now.

² New entry--plans to sell technology and equipment only.

Source: Institute for Defense Analyses

TABLE 6. FOREIGN PRODUCTION SOURCES OF CARBON FIBER (PAN BASE)-1984

Country	Organization	Trade Name	Production capacity metric tons/Yr	Precursor Source
Japan	Toray Industries	Torayca	2780	Toray Toho Asahi Courtaulds*
	Toho Beslon	Besfight	2250	
	Asahi-Nippon	Carbolon	400	
	Mitsubishi Rayon	Pyrofil	260	
United States	Courtaulds	Grafil	770	Courtaulds Courtaulds Courtaulds
	RK Carbon Fibers, Ltd.	RK Carbon	450	
France	SOFICAR (Toray-Elf)		660	Toray
West Germany	SIGRI	Sigrafil	150	Courtaulds
	ENKA		660	

*Courtaulds also supplies precursor to other carbon fiber producers, including Hercules.

Source: Institute for Defense Analyses

Silicon carbide whiskers are being produced by Tokai Carbon Company under the tradename Tokomax. The whiskers are competitive with ARCO's silicon carbide whiskers, which are derived from rice hulls. Whisker production capacity at Tokai is estimated at 24 tons a year.

Alumina Fiber. Alumina fiber is produced by Sumitomo Chemical Company in a pilot plant which can produce only a few tons per year. It is available as continuous fiber in yarn form or as woven fabric in plain or 8-harness satin weave patterns. Composites of alumina fiber in aluminum matrices and epoxy matrices have been produced experimentally. Because of U.S. interest, Sumitomo is considering the possibility of producing the material in the United States.

Aramid Fibers. Imported DuPont Kevlar is used in a number of applications in Japan. Meanwhile, a potential competitor to Kevlar has been developed by Teijin Ltd. and is named HM-50. Patents have been obtained for HM-50 in seven countries, including the United States. This material is being evaluated as a reinforcement for tires, other rubber products and plastics.

France

French aerospace companies have been very aggressively pursuing the use of composite materials in components for many years. The recent announcement of carbon fiber production facilities by SOFICAR will enable the French to take a significant step toward self-sufficiency in carbon fiber composites (See Table 6). SOFICAR (Elf Aquitaine/Pechiney/Toray) is expected to begin using Toray PAN fiber precursor in 1984 to make 300 tons a year of carbon fiber for European markets which now use Toray fiber. European consumption of carbon fiber in 1980 was 300 tons. The only carbon fiber production in France has been at Serafim, which uses PAN precursor produced by Rhone-Poulenc. However, Rhone-Poulenc has stopped supplying PAN precursor, and it is believed likely that Serafim will discontinue carbon fiber production when SOFICAR's new plants become operational.

A French source (Vetrotex St. Gobain) of high-strength R-glass fiber is supplying material to other European countries and is also trying to enter into the U.S. market for high-strength glass in competition with Owens-Corning S-2 glass. France does not yet have a production source for an aramid fiber but can obtain the material from the German Enka Company. There is no production of boron fiber in France, but the French propulsion company, SNPE, could probably produce it if the need arose. This company developed the B₄C coating process for boron fibers which has been licensed to AVCO in the United

States. The demand for boron fibers is not large, however. Other fibers, such as silicon carbide and alumina, are not produced in France.

United Kingdom

The major composites industries in the United Kingdom are listed in Table 7, which includes most of the organizations involved in structural or industrial composites. The table omits manufacturers of insulation and some consumer goods.

Although carbon fibers got their start in the United Kingdom in the mid-1960s, industrial and aerospace uses of carbon fibers have not been large, amounting to only 25 percent of United Kingdom carbon fiber production. Courtaulds is now the sole producer of the special grade of acrylonitrile precursor fiber used for carbon fiber production. Recently, Courtaulds joined the Hysol Division of the Dexter Corporation in establishing a new company called Hysol-Grafil which will operate plants in the United Kingdom and the United States as a supplier of fibers and prepreg.

Courtaulds is one of three companies in the United Kingdom that were licensed by the National Research Development Corp. in 1968 to produce carbon fiber from PAN precursor. Courtaulds produces its own acrylonitrile monomer and has developed improved techniques for PAN precursor fiber production and conversion to carbon fiber. This process was licensed to Hercules in 1970, but the Hercules facility in the United States has now become more dependent on Japanese precursor. Courtaulds' (now Hysol-Grafil) carbon fibers are marketed worldwide, and 75 percent of production is exported to the Far East. Some Courtaulds PAN precursor is sold to several carbon fiber producers in the United States (including Hercules) and Europe. Japanese carbon fiber producers have their own sources of precursor and require no imported precursor.

Courtaulds produces acrylonitrile at the rate of some 100,000 tons a year, primarily for the textile industry. Of this total, 6,000 tons is specially designated for use in the production of 1,000 tons of PAN. Courtaulds' has six carbon fiber machines with capacity of 350 tons a year (see Table 6). Meanwhile, Hysol-Grafil planned to install a 150-ton carbon fiber plant in the United States during 1984-85.

Interest in high-strength carbon fibers for primary aerospace structures has prompted Courtaulds to place renewed emphasis on precursor quality through purification and other modifications.

TABLE 7. COMPOSITES INDUSTRIES IN THE UNITED KINGDOM

Product	Producers
Precursor PAN	Courtaulds
Fiber, Carbon	Courtaulds RK Carbon Fibers
Weaving	Carr Reinforcements Bridon Composites
Resins	I.C.I. Ciba-Geigy Shell
Prepreg	Fothergill & Harvey Ciba-Geigy Cyanamid-Fothergill Specmat Ltd. Hyfil Strucol
Fabricators	British Aerospace Westland Helicopters Lucas Bristol Composites Bridon Composites Dunlop Ciba-Geigy Bonded Structures Rolls Royce Slingsby Engineering Advanced Composite Components Cyanamid Fothergill Lear Fan AVCO Engineering Ltd. Fothergill Rotorway Composites Dowty Rotol
R&D Groups	Royal Aircraft Establishment Atomic Energy Research Establishment Bristol University Cambridge University Fulmer Research Institute

Source: Institute for Defense Analyses

RK Carbon Fibres, Ltd., a subsidiary of RK Textiles Ltd. in the United Kingdom, has embarked on an ambitious program to supply high-grade carbon fiber as well as processing technology to composites industries throughout the world. The parent company has been developing a process for converting PAN precursor to carbon fiber at lower than present costs, but it has no captive source of PAN. RK expects to be able to tap several sources of PAN. One of the company's objectives is to set up turnkey plants in various countries, and negotiations on several possible installations have been in progress. In March 1983, RK Carbon announced the opening of a new \$4.5 million plant near Inverness, Scotland, which has a capacity of 200 tons a year of carbon fibers.

There is no production of other fibrous materials, such as high-strength glass, aramid, boron, alumina, and silicon carbide in the United Kingdom. Needs for these materials are small and are met through imports. R glass from France, as well as S glass from the United States, has been used in British Aerospace programs, but S glass is difficult to purchase because of U. S. export control laws.

West Germany

The composites industry in West Germany is limited in size and scope. Chemical companies like Hoechst and Bayer produce textile grade acrylonitrile fiber, which is used in small amounts to produce carbon fiber. However, the only current supplier of carbon fiber in West Germany is SIGRI, which produces SIGRAFIL and SIGRATEX from PAN-based precursor reportedly supplied by Courtaulds (See Table 6). A new facility for production (100 tons per year) of oxidized PAN fibers is reported to have started up in the past 2 years. Although this is the first step in production of structural-grade carbon fiber, the grade of precursor used for industrial grade (preoxidized) carbon fiber is generally lower than that used for structural fiber. SIGRI is also believed to be emphasizing very large tow material (320,000 filaments) instead of the smaller tows (1,000, 3,000, 6,000, and 10,000 filaments) commonly used in the aerospace industry. In any case, SIGRI is not a major supplier of structural carbon fiber in Europe, although it may possess the technology to become one. SIGRI is the parent company of Polycarbon (U.S.), which converts mostly rayon precursor to carbon fiber for industrial applications and aircraft brakes. SIGRI is also reported to have bought carbon fiber from Toho-Beslon.

A new 200 to 300 ton per year carbon fiber plant will be built by AKZO (parent company of ENKA) somewhere in West Germany or the Netherlands, using technology and precursor from

Toho-Beslon in a joint venture among Enka, Toho-Beslon, and Celanese. This facility was to be on stream by 1985 and will be aimed at the structural fiber market in Europe, competing with new plants being built in France by Toray-Elf Aquitaine.

Another major facility for fibers will be a 5,000 ton per year plant to be built by Enka for the production of aramid from its own raw materials. This material, similar to DuPont's Kevlar, has been the subject of patent litigation.

Prepreg material is available from SIGRI, which has produced prepreg containing Toho-Beslon carbon fiber. The only other company which reportedly supplies prepreg material is A. Krempel Soehne, GmbH, but details of its products are not available.

Belgium

Belgium is not a producer of composite materials, but such U.S. companies as 3M, Hexcel, Narmco, and Clark-Schwebel have established factories in Belgium. 3M supplies adhesive products, Hexcel and Narmco are primarily suppliers of prepreg and honeycomb products, and Clark-Schwebel is a textile machinery and products company. Some fabrication work has been conducted in Belgium for General Dynamics in Fort Worth.

Israel

In recent years, Israel has been building up its capabilities in many areas of technology, including composite materials. Carbon fibers are being produced in a new plant by Afikim Carbon Fibers located at Kibbutz Afikim. These fibers are based on polyacrylonitrile precursor and are made available as an oxidized PAN for general use as a replacement for asbestos, and as high-strength and high-modulus fibers for structural applications. The next step in this company's planning is to provide unidirectional prepreg of aerospace quality. The production capacity and source of the PAN precursor are not known.

Two new manufacturing facilities have been built for the production of composites at Israeli Aircraft Industries Ltd., Karmiel. There are additional facilities at military establishments.

Israel had previously sought to purchase carbon fibers and prepreg material from a U. S. supplier but reportedly was unable to do so because of export control regulations. Recently, approval has been granted Israel to acquire U.S. technology.

Italy

There are no producers of carbon fibers or aramid fibers in Italy at present, but serious consideration is being given to the establishment of a carbon fiber and prepreg plant by ANIC, a state-owned chemical company which may also produce epoxy resins.

South Korea

Japan exports some fibers to South Korea for fabrication of sporting goods. Although the industry in South Korea is very limited, some prepreg capability has been established. It is also known that filament-winding capability exists in Korea, and that research is being conducted, but details are not available. The major organizations reported to be involved in advanced composite reinforcement materials are the Korea Advanced Institute of Science and Technology, the Korea Institute of Machinery and Metals, Oriental Industry Co. Ltd., and Han Kuk Fibre Glass Co., Ltd.

Taiwan

Taiwan is also a user of carbon fiber for sporting goods, using fibers and preregs imported from Japan and the United States. In fact, Taiwan is the second largest consumer of carbon fibers in the free world.

Soviet Union

Data regarding the Soviet Union is not available. However, it is thought that the USSR may account for as much as one-quarter of the non-Communist world's production of PAN and it may also have a small capability in aramid fiber production.

IV. Assessment of Current Competitiveness

Comparison of the Status of Fiber Technology in the United States and Other Countries

It is not possible at this time to evaluate the relative competitiveness of the different countries that produce fiber reinforcement materials on the basis of market shares, production costs, or total sales. The use of carbon and other types of fibers as reinforcement materials is still relatively new, and accurate data on such things as annual production totals, annual sales, and annual production costs either do not exist, or have not been made public. However, current sales of carbon fibers to the U.S. aerospace industry are estimated at about 2 million pounds, or about 65-70 percent of estimated 1982 production capacity. As mentioned earlier, carbon fibers and aramid fibers are the only two types that are used to any significant degree in the production of composites. The other fibers are used essentially for experimental purposes.

Table 8 is an attempt to portray the relative standing of various countries in fiber technology in an informal table prepared by an expert in the field on the basis of often incomplete data (and, in some cases, no data at all). Information on USSR capabilities in fiber is particularly hard to obtain, and blank spaces in the table indicate an absence of information. Although Table 8 is a subjective assessment, it does provide a rough indication of comparative country strengths.

Some indication of present and future competitiveness can also be drawn from Table 8. A country that has made substantial progress in developing a particular type of fiber can be expected to have a good position in the current marketplace or to be in the best position to enter commercial production if demand for the fiber arises. Furthermore, it is likely that such a country will have more advanced production processes and a more competitive cost structure.

At the same time, however, it should be mentioned that advanced technological status is no guarantee of subsequent profitable production. A country with lower labor costs, lower environmental protection costs, or greater availability of raw material may be in a better position to manufacture a particular fiber than the country that first developed the technology.

As reflected in Table 8, the United States has done the most work in developing carbon fibers based on the precursor materials rayon and pitch, and also leads the world in

TABLE 8. ONE ESTIMATE OF
COMPOSITES TECHNOLOGY COMPARATIVE
COUNTRY STRENGTHS--FIBER TECHNOLOGY

Technology Item	U.S.	USSR	U.K.	JAP	FR	W. GERM	ITALY
CARBON GROUP							
Precursor (Rayon)	●●●						
Precursor (PAN)	●	●	●	●●●	●	●	
Precursor (Pitch)	●			●			
Carbon (Rayon)	●●●						
Carbon (PAN)	●	●●●	●	●●●	●	●	
Carbon (Pitch)	●			●			
ARAMID							
Kevlar●	●●●	●					
BORON							
Boron on C core	●						
Boron on W core	●						
Boron/B ₄ C coating	●				●		
BORSIC●	●						
SILICON CARBIDE							
SiC on W core	●	●					
SiC (polycarbosilane)				●			
SiC whiskers	●						
ALUMINA							
Fiber FP	●						
Alumina				●			

● Uncertain

Source: Institute for Defense Analyses

producing carbon fibers from these two precursors. Japan, on the other hand, leads the world in producing the precursor polyacrylonitrile (PAN), and also produces more carbon fibers from PAN precursor. U.S. capabilities in PAN technology, and in production of carbon fibers from PAN, rank second to those of the Japanese. Soviet capabilities in producing carbon fibers from PAN are difficult to pinpoint, but if fragmentary evidence is correct, it appears that Soviet production of carbon fibers from PAN may be as much as one-fourth of the non-Communist world's production.

Unlike the situation with respect to carbon fibers, where the United States and Japan compete vigorously, the United States (or, more specifically, DuPont) has no close competitor in aramid fiber technology or production. The USSR apparently has a small capability in aramid technology.

Boron fiber technology is centered in the United States, but the Soviets have been investigating boron composites, and it is believed that boron fibers may have been produced in the USSR. The B₄C coating process used in the United States was licensed from France, although French boron fiber production is virtually nil. Silicon carbide fiber technology based on the deposition process results in fibers approximately 5-8 mils in diameter is essentially found in the United States, but some capability apparently exists in the USSR. The substrateless micron-sized silicon carbide fibers derived from polycarbosilane are almost solely Japanese, although some research work is in progress in the United States. The smaller diameter Japanese fibers have many advantages in metal infiltration and uniformity of matrix. Alumina fibers of two types are being developed, the high-purity FP fiber being a United States product entirely, the less pure alumina being a Japanese development.

V. Future Competitiveness

Potential New Uses for Fibers

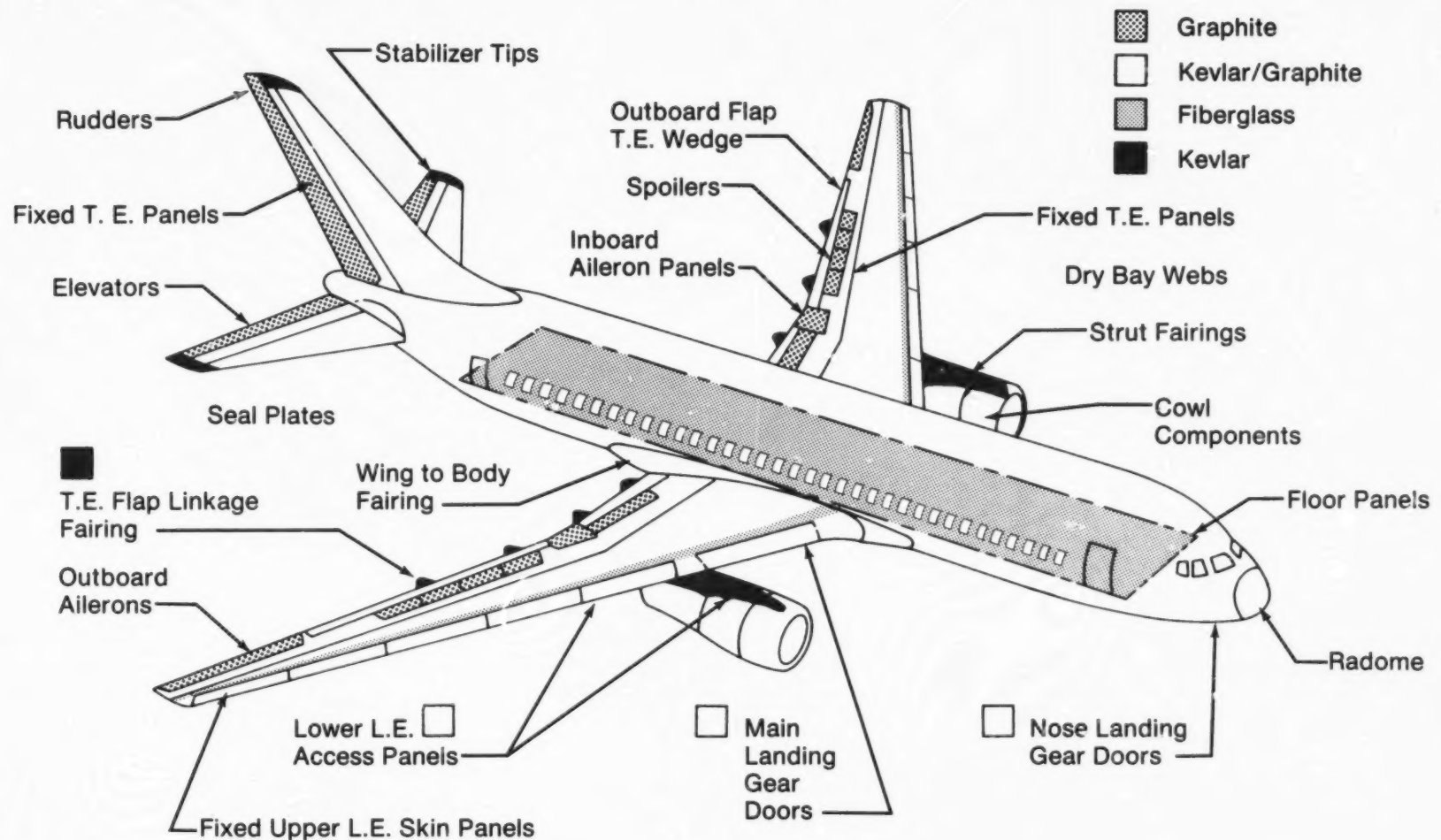
Worldwide demand for carbon and aramid fibers as composite reinforcement materials will continue to grow as new uses for composites are developed. Many of these new uses will come about as composite materials containing fiber reinforcements are substituted for other materials used in military hardware. The U.S. military establishment is a large user of composite materials containing carbon fibers, although actual data on the quantities of carbon fibers used by the armed forces are not released. Composite materials containing carbon (and possibly other) fibers will be used in the future in such military hardware items as rocket launchers, portable bridge, shipboard satellite communications antennas, shipboard missile domes, and missile cases.

In the civilian sector, composite materials reinforced with carbon and possibly other types of fibers will continue to find their greatest use in the aerospace industry, which currently utilizes well over half of the carbon fibers incorporated into composite materials in the United States. Fiber-reinforced composites will probably be developed for such aircraft parts as landing gear doors, wing structures, and jet engine components in the near future. Ultimately, new aircraft will be designed that will use fiber-reinforced composites as their primary structural materials. Figures 3 through 9 show how composites are used in aircraft parts.

Although composites reinforced with the various types of fibers are not used to any notable degree in the automobile industry, advanced composites may eventually be used in the production of certain automobile parts now made of steel, aluminum, or other metals. As in other manufacturing areas, parts made of advanced composite will provide equivalent performance in combination with significantly decreased weight. Advanced composite materials may initially be used for such vehicle parts as drive shafts, bumpers, and body structures. While the automotive area offers the best hope for large volume non-aerospace consumption of composite materials, lower-priced conventional metals makes its future market growth uncertain.

It also seems likely that advanced composite materials will be used to an increasing extent in agricultural machinery. Because of the relatively light weight of composite materials, their use will make it possible to increase the length and width of agricultural machines, thereby decreasing the weight per square inch on the soil. Similarly, advanced composites may eventually be incorporated into mobile cranes and aerial ladders in order to make them lighter and longer.

FIGURE 3
Composite Structure on the Boeing 767

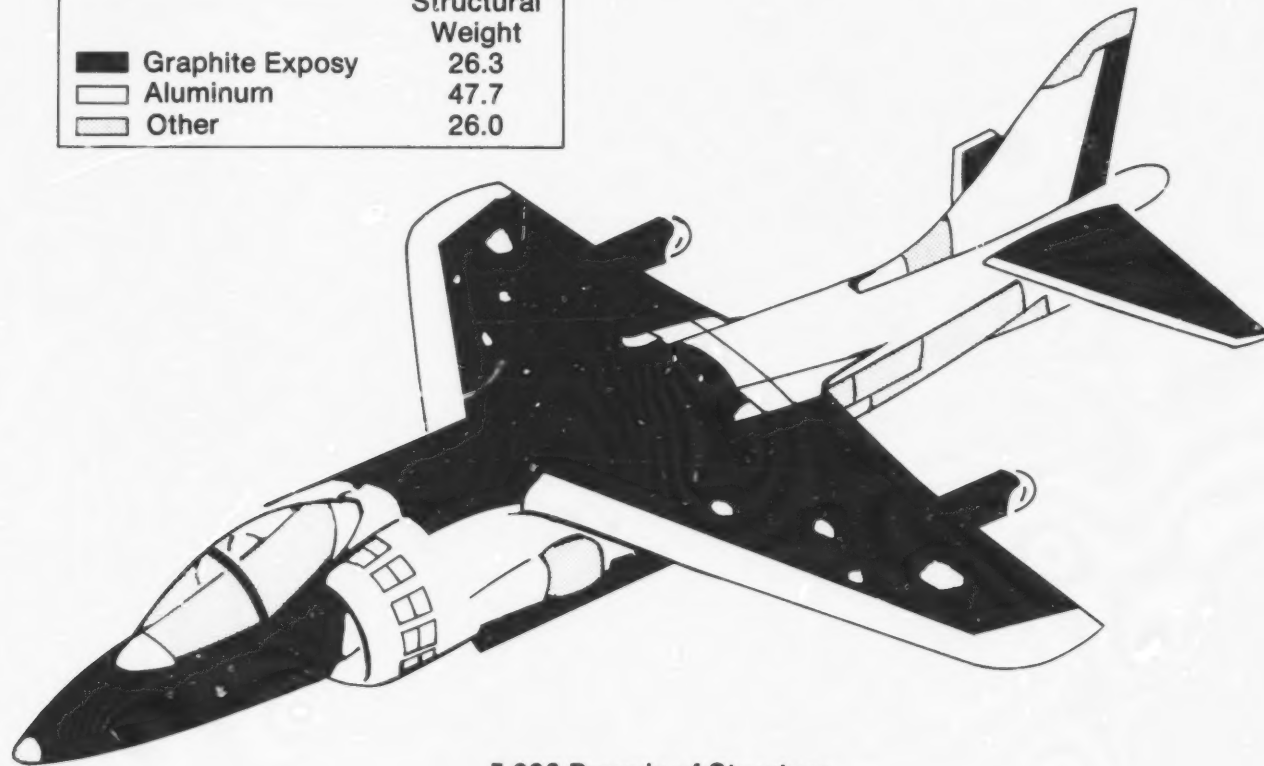


Source: Institute for Defense Analyses

FIGURE 4

Carbon Composite Structures on the AV-8B

	Structural Weight
■ Graphite Exposy	26.3
□ Aluminum	47.7
□ Other	26.0

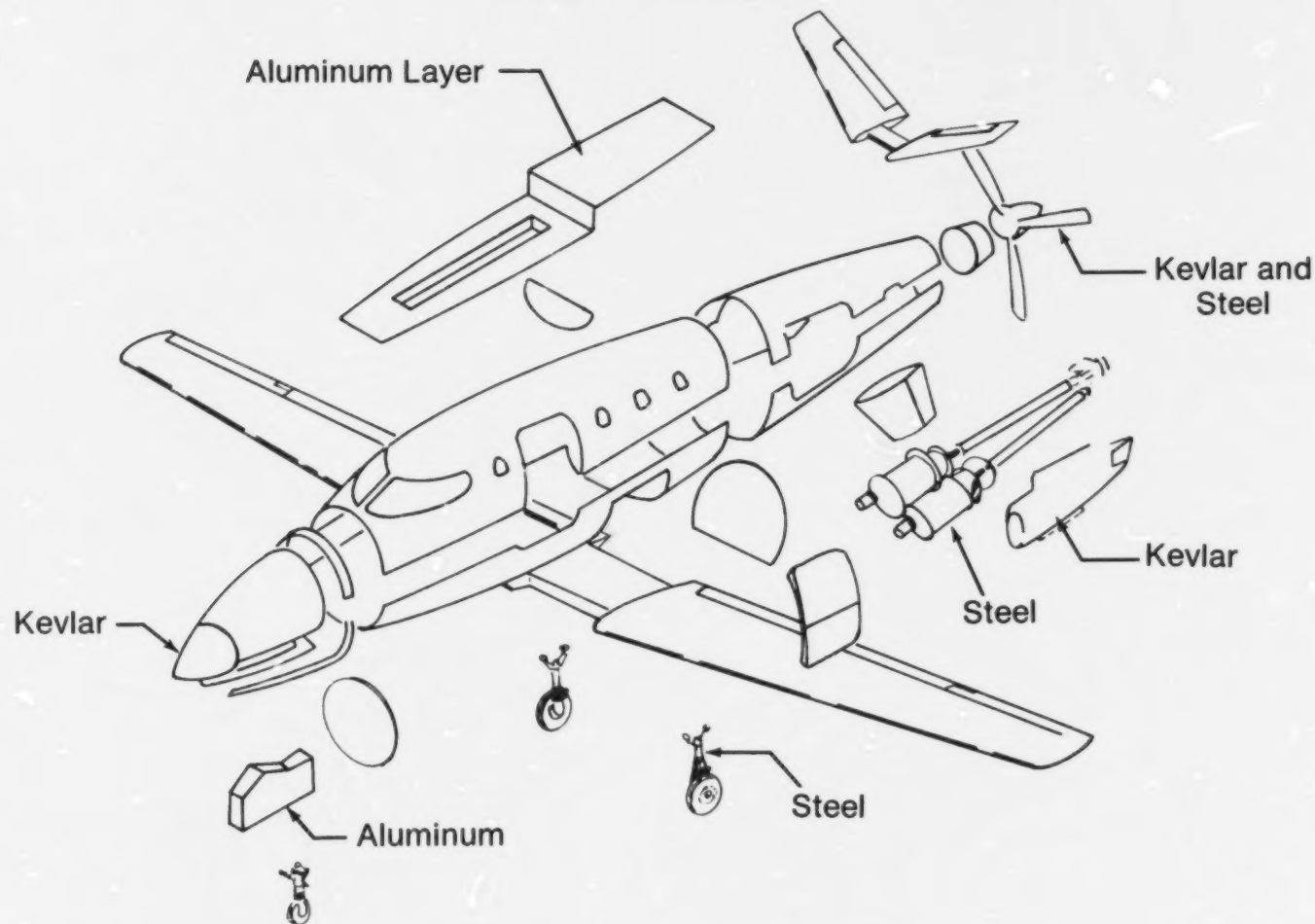


5,006 Pounds of Structure
1,317 Pounds of Graphite Epoxy

Source: Institute for Defense Analyses

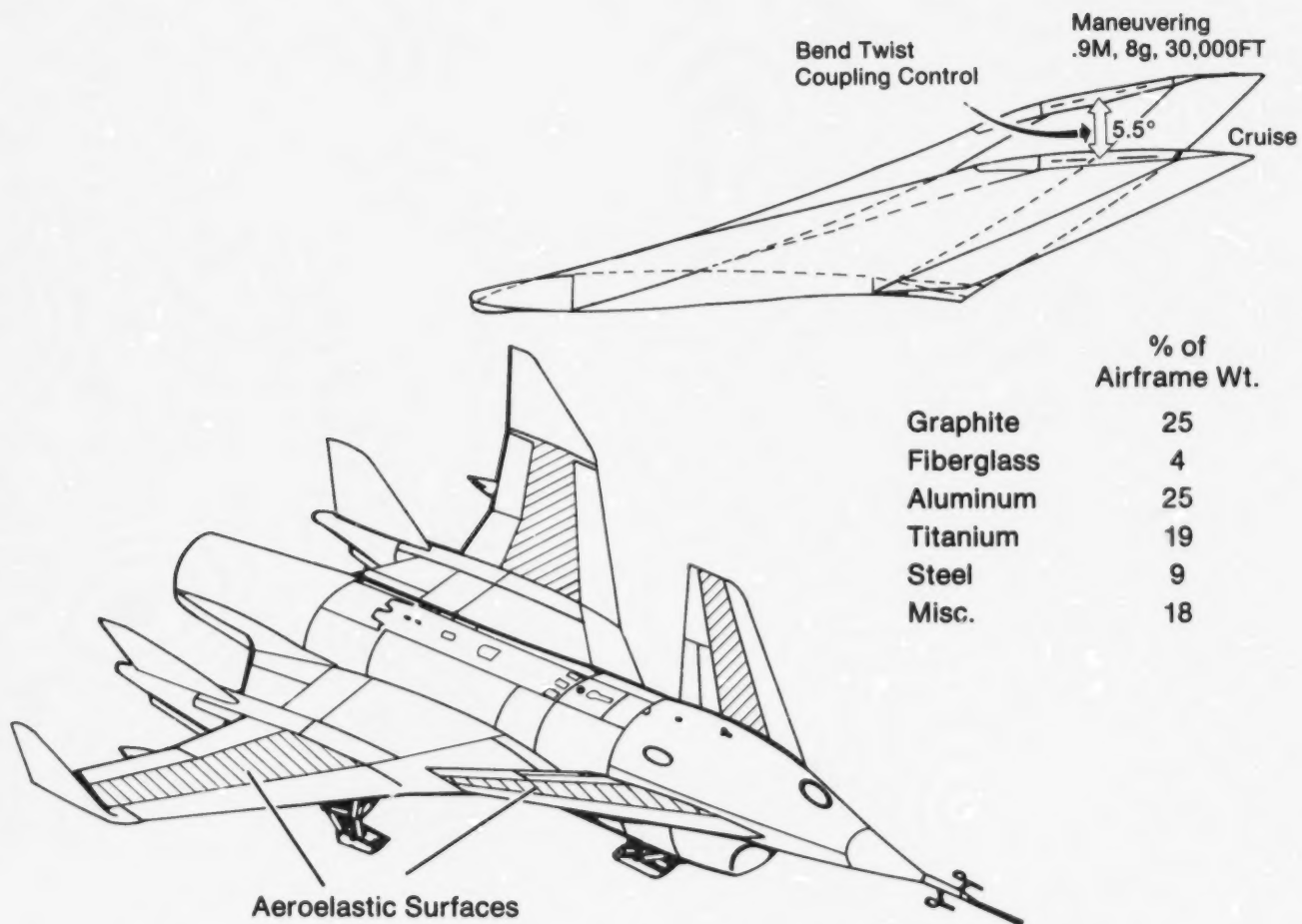
FIGURE 5

Airframe Elements of the All-Carbon-Composite Lear Fan 2100



Unlabeled Components are Carbon/Epoxy

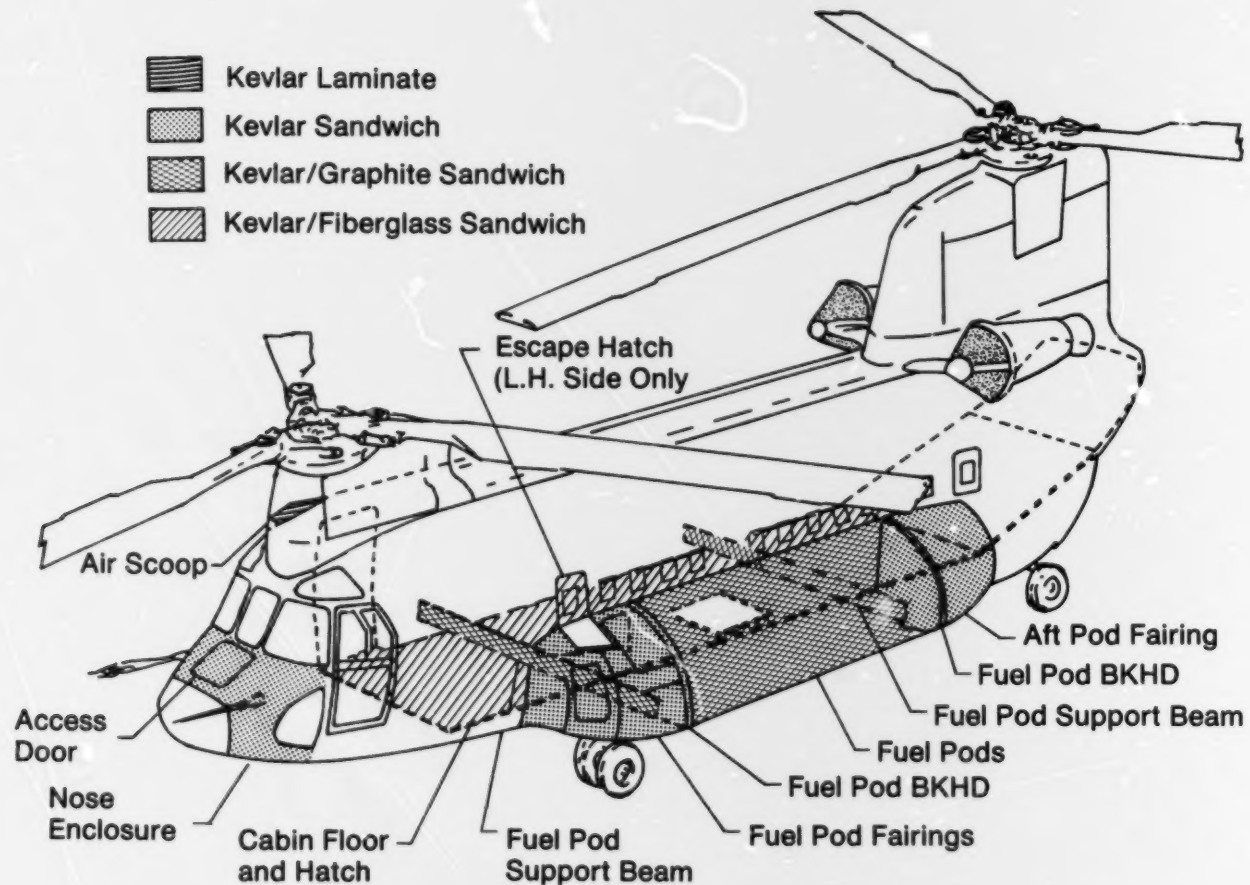
FIGURE 6
HiMAT Advanced Structural Composite Applications



Source: Institute for Defense Analyses

FIGURE 7

Boeing 234 Helicopter Composite Applications



Source: Institute for Defense Analyses

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FIGURE 8

Sikorsky S-76 Helicopter Composite Applications

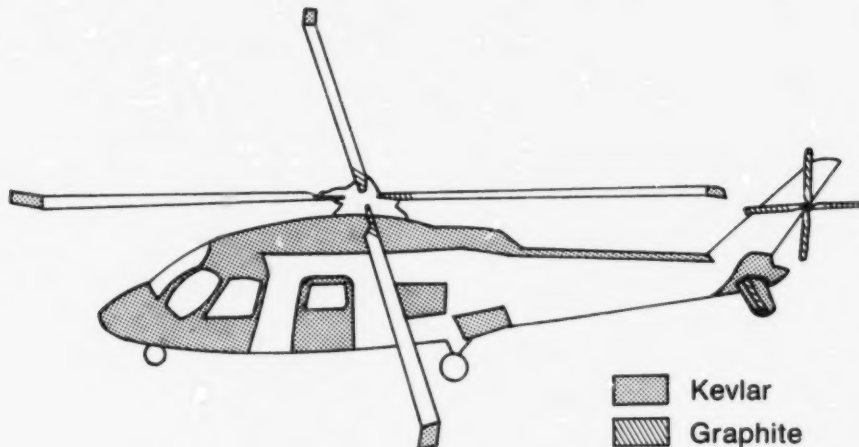
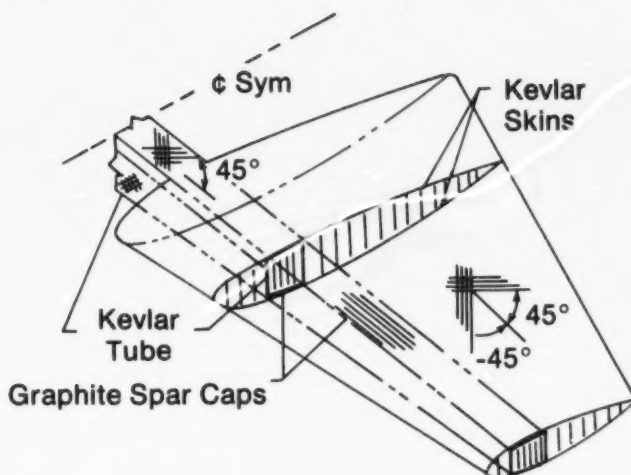


FIGURE 9

S-76 Composite Horizontal Stabilizer



- Kevlar-49/Epoxy Skins $\pm 45^\circ$ (Nomex Honeycomb Core)
- Kevlar-49/Epoxy Torque Tube $\pm 45^\circ$ (Aluminum Honeycomb Core)
- Graphite/Epoxy Spar Caps. 0°

Medicine may also be an area where advanced composite materials will come increasingly into play. Among other things, composite materials may be used to improve the performance of external and implantable prosthetic devices and as lightweight, high-performance substitutes for standard metals in the manufacturing of orthopedic equipment.

Carbon Fibers

Table 9 shows the estimated 1984 annual carbon fiber production capacities of companies in the United States, Japan, the United Kingdom, France, West Germany, and Israel. There was large surplus capacity as of 1984, and even a strong rate of growth in consumption through 1990 will leave an overall excess in production capacity, even without any expansion of capacity after 1986. A halt in the growth of production capacity seems unlikely, however, since manufacturing companies in many countries are trying to develop their own domestic sources of material supply.

Table 9

Carbon Fiber Production Capacity by Country and Firm, 1984

<u>Country</u>	<u>Producer</u>	<u>Precursor</u>	<u>Capacity (000 lbs/yr)</u>
United States	Union Carbide	PAN	800
	Union Carbide	Pitch	1,000
	Hercules	PAN	1,300
	Celanese	PAN	600
	Hitco	PAN	250
	Great Lakes Carbon	PAN	400
	Stackpole	PAN	250
	Hysol-Grafil	PAN	330/(700)
	Polycarbon	Pitch & Rayon	110
	Avco	PAN	110
Japan	Toray Industries	PAN	2,780
	Toho Rayon	PAN	2,250
	Asahi Nippon Carbon Fiber	PAN	400
	Nippon Carbon	Rayon	130
	Mitsubishi Rayon	PAN	260/(700)
	Sumika-Hercules	PAN	(800)
	Kureha Chemical	Pitch	300
United Kingdom	Courtaulds	PAN	770
	R. K. Textiles	PAN	450
France	SOFICAR	PAN	660/(700)
West Germany	Sigri	PAN	150
	Enka	PAN	660/(1100)
Israel	<u>Afikim</u>	PAN	<u>200</u>
Total	28 Producers		18,360

Note: Capacities in parentheses are expected to come onstream in 1985 and 1986, and they are included in the total. Capacity may also be expanded at Hercules and Stackpole during the next few years.

Table 10 shows estimated consumption patterns by world geographical region for 1984 and 1987, as estimated, by several U.S. manufacturers. Table 11 shows estimates by Toray, Japan's leading carbon fiber producer. While Toray's estimate of 1984 world consumption is higher than the U.S. estimate, both the domestic and the Toray estimates of current U. S. demand are about the same. However, Toray's 1987 projections of both U.S. and world demand are somewhat lower than the American projections. Regardless of which estimate turns out to be more accurate, capacity will remain much higher than demand.

Table 10
ESTIMATED WORLD CONSUMPTION OF CARBON FIBERS (000 lbs)
BY INDUSTRY
(Compiled from American Sources) (000 lbs)

	<u>1984^{1/}</u>	<u>1987</u>
Western Europe		
Aerospace	330	880
Sports and Recreation	200	350
Industrial	180	400
Subtotal	<u>710</u>	<u>1550</u>
United States		
Aerospace	1110	3300
Sports and Recreation	400	500
Industrial	300	620
Subtotal	<u>1810</u>	<u>4420</u>
Japan		
Aerospace	50	130
Sports and Recreation	500	800
Industrial	350	1100
Subtotal	<u>900</u>	<u>2030</u>
All Other	500	1000
Total	<u>3920</u>	<u>9000</u>

^{1/} Survey conducted in 1984 by SRI International for DOC.

Table 11

ESTIMATED WORLD CONSUMPTION OF CARBON FIBERS,
BY REGION OR COUNTRY
(000 lbs)

	<u>1984</u>	<u>1987</u>
United States	1870	3234
West Europe	704	1342
Japan	1276	2024
Other	<u>858</u>	<u>1144</u>
Total	4708	7744

Source: Toray Industries.

Table 12 shows estimates of U.S. consumption of carbon fibers in 1985, 1987, and 1990, based on a more recent survey. Growth in demand is expected to be strong through 1990. Demand from the aerospace sector will grow at a healthy 20 to 25 percent, and demand from the industrial sector will grow at about the same rate. Sports and recreational uses are expected to become less important as a percentage of overall use, while automobile use is expected to increase slowly through 1990.

Table 12

PROJECTIONS OF U.S. CARBON FIBER CONSUMPTION BY INDUSTRY TO 1990
(000 lbs)

	<u>1985</u>	<u>1987</u>	<u>1990</u>
Aerospace	2065	3400	6300
Sports and Recreational	500	470	750
Industrial	385	630	1200
Auto	<u>0</u>	<u>50</u>	<u>150</u>
Total	2950	4500	8400

Note: DOC survey conducted in 1985.

Trends in Carbon Fiber Research and Development

Although the strength of carbon fibers has steadily been improved, significant amounts of R&D dollars are being spent to push fiber strength well above the one million pounds per square inch level. While many research efforts are being made to find new and better ways to use carbon fibers, other areas of importance are also being pursued. These include:

- Upgrading the performance of adhesive material.
- Improving process technology.
- Innovations in design.
- Nondestructive testing methods.
- Lower-cost testing methods.
- Increasing stiffness with good strength.
- Improving compression strength.
- Improving composite toughness.
- Improving hot/wet performance.
- Improving material manufacturability.
- Developing automated parts fabrication methods.
- Developing materials scientists and engineers in fiber technology and design.

World Competition in Carbon Fibers

Because carbon fibers are produced around the world and are traded in international markets, they are subject to competition in price, quality, and dependability of supply. The price and quality of certain types of foreign-made carbon fibers, in combination with historic supply relationships, mean that almost 20 percent of the U. S. carbon fiber market will continue to be held by imports. This figure may increase if Japanese efforts to produce high quality, low-cost fiber from pitch are successful. Conversely, U. S. domination of prepreg and fabrication technology accounts for the export of domestic carbon fibers and the reexport of foreign produced carbon fiber to both Japan and Europe. The foreign operations of American companies, either as wholly-owned subsidiaries or as joint ventures, are a major factor in the overseas prepreg business.

The aerospace industry is the major user of carbon fibers today and will remain the major user in the foreseeable future. Sales of carbon fibers to U.S. aerospace companies are currently around 2 million pounds, or about 75 percent of U.S. production.

Most, if not all, of the techniques for the fabrication of advanced composites are so specialized, especially when combined with design engineering and knowledge of their capabilities, as to be subject to export controls, if not classified.

The carbon fiber industry in the United States is reasonably healthy and can be expected to grow, particularly as a supplier to the aerospace industry. However, increased competition can also be expected, particularly from the Japanese.

In the near term the domestic industry will tend to be hampered by overcapacity at home and competition from high quality, low-priced fibers from overseas. The dilemma that domestic carbon fiber producers face, is that their prices are high because their costs are high. They cannot lower their prices until increased volume lowers the fixed cost components in prices; but volume cannot be increased as long as prices remain high.

Aramid Fibers

While DuPont's aramid fibers, marketed under the registered trade name Kevlar, are by far the most widely-used aramid fibers, other countries now produce, or plan to produce, aramid fibers. In the Netherlands, AKZO has announced that it plans to start up a plant to produce 11 million pounds per year of an aramid fiber with the registered trademark Twaron in late 1985. DuPont, which claims that Twaron is both chemically and physically identical to Kevlar, is in litigation with AKZO in U.S. Federal court and before the International Trade Commission, claiming infringement of DuPont's patents by AKZO. DuPont has also filed an infringement suit against West Germany's Enka, which produces an aramid fiber that has been used in tires for a number of years. Enka's production capacity is being expanded from 200,000 pounds to 10 million pounds. Additional infringement suits have been filed by DuPont in the United Kingdom, France, and Italy. The principal DuPont process patents run until late 1990, while key DuPont product patents generally remain in force until 1992.

Future Market Prospects for Aramid Fibers

As mentioned earlier, DuPont is the only U.S. manufacturer of aramid fibers. Sales levels and market volumes are information that DuPont considers proprietary, but the following general comments can be made about future prospects.

Kevlar will continue to be used as a reinforcement material in many rubber products, ranging from tires to high pressure hoses, power transmission belts, and conveyor belts. In the past, sales of Kevlar as a rubber-reinforcing material have accounted for a majority of sales, and DuPont expects the total volume of Kevlar sold for this purpose to grow significantly. However, the percentage of total Kevlar production sold for this purpose is expected to decline as aramid fiber is used more extensively for other purposes.

A newer market for Kevlar fiber has been its use in the creation of bullet-proof materials. In 1983, the U.S. military stepped up its procurement of protective vests and helmets, and demand for Kevlar for such protective clothing is expected to remain significant, at least in the short term. Volume may drop, however, as military and civilian markets for such clothing reach high levels of saturation.

Perhaps the strongest demand for Kevlar now is as a replacement for asbestos in various automotive applications. Research has shown that asbestos fibers are a hazard to human health, and substitutes for asbestos are in demand. As a result, demand for Kevlar to replace asbestos in such car parts as brake linings, clutch facings, and gaskets is now growing rapidly. For critical high-temperature applications, Kevlar in the form of short cut fiber or pulp appears to be best. This market now uses a significant percentage of total sales of Kevlar.

Two Prospective Aramid Fiber Competitors

Future competition for Kevlar could come from such products as Teijin's HM-50 and Allied's high strength polyethylene, known as Spectra 900. HM-50 is an aramid, but it is produced from a polymer with a different chemical composition than the one used for Kevlar. HM-50 is available only in sample quantities from Teijin, a Japanese firm, and no announcement of commercialization has been made. Allied's Spectra 900 is a high-strength polyethylene with reportedly even higher strength and lower density than Kevlar. Allied has announced plans to commercialize the product, with the first commercial quantities available in 1986/87. The product may compete with Kevlar in rope applications and ballistics. It may also compete in certain composite applications where higher temperature properties are not required.

DuPont is the world's leader in aramid fiber development and production. Moreover, as a result of its worldwide experience in production, marketing, and product development, DuPont's Kevlar should remain as the aramid fiber leader for the foreseeable future. However, future competition will be strong both from foreign aramid producers and from new materials with characteristics similar to Kevlar.

VI. Implications and Government Policy Options

Transfer of Technology to Foreign Producers

The development of advanced composite materials that use fibers is being undertaken on a multi-national basis, and there is a high degree of inter-dependence and technology transfer. For the most part the industry is in the advanced R&D stage, although several products have recently emerged into the commercial application stage. The United States appears to be the world leader in the development of composite materials, particularly in composites for aerospace structures, but U.S. leadership could be jeopardized if technology is easily obtained by foreign producers. In addition, the transfer of composite materials themselves to foreign manufacturers could cause domestic manufacturers to lose advantages at the product level. For these reasons, and given the interest in current and potential military applications, a review of current U.S. controls on the transfer of composite materials and technology might be appropriate. The following areas could be included in such a review:

1. Methods to advise and familiarize industry, universities, technical societies, and government personnel with export control policies and procedures.
2. Development of a procedure for identification and control of emerging technology at an early stage in its development.
3. Development of procedures for disseminating government-sponsored and developed technical data to U.S. industry.
4. Increase efforts to acquire and exploit foreign technology.

Material Availability

Although the United States has the world's largest composite fabrication capacity, it has become dependent on foreign sources for many of the raw materials used in advanced composites. Since composites are increasingly used in defense systems, this dependency could affect the country's ability to sustain a mobilization effort. A review of the nation's mobilization needs could be conducted by the appropriate federal agencies to determine:

1. If raw materials for advanced composites should be included in the strategic stockpile.

2. How the increased use of composite materials affects stockpile goals for other raw materials, such as aluminum and titanium.
3. How and if other defense programs, such as the Defense Production Act, could be used to encourage domestic production of these raw materials.

Data Availability

Data on the production, consumption, and costs of most advanced composite materials is extremely limited. Consideration could be given to a concerted effort to collect data relating to this emerging industry. In particular, an industry survey of the U.S. carbon fibers industry might be especially helpful for industry planning in light of current excess capacity.

Government Support of Educational Facilities

There appears to be a lack of educational facilities for developing materials scientists and engineers in the advanced composites areas. One option would be for the National Science Foundation, the Department of Education, and other Federal agencies to increase their fellowships, research, and curriculum development activities with U.S. universities in the fields of advanced composite materials.

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